A compilation of dissolved noble gas and N2/Ar ratio measurements collected from 1999-2016 in locations spanning the globe

Website: https://www.bco-dmo.org/dataset/743867
Data Type: Cruise Results
Version: 2
Version Date: 2022-01-17

Project
» Carbon Dioxide Dynamics in Mode Water of the North Atlantic Ocean (CarboMODE)
» Measurement of Helium Isotopes, Tritium, Noble Gases, and Radiocarbon (EPZT Noble Gases He Tritium)
» The Marine Dissolved N2/Ar Ratio, A Tracer for Deep Ocean Denitrification? (N2:Ar Deep Tracer)
» Characterizing the Formation, Nature, and Export of Weddell Sea Bottom Water using Noble Gases and Transient Tracers (Weddell Sea Tracers)
» Measuring Diapycnal Mixing in the Upper Ocean therMocline using Noble Gas Supersaturation (Measuring Diapycnal Mixing)
» GEOTRACES Atlantic Section: Measurement of Helium Isotopes and Tritium (NAT He and Tritium)
» Tracers of Biological Productivity and Gas Exchange (Tracers of Bio Prod and Gas Exchange)
» Is There an Ocean Primary Production Paradox(OP3)? (OP3)
» The Biological Carbon Pump in the Subtropical North Pacific Ocean: Mechanisms of Nutrient Supply (C Pump in Subtropical N Pacific)
» Net Biological Oxygen Production at the Japanese JGOFS Time-Series Station (Net Bio O2 Prod JGOFS)
» Gas Tracers of Net Biological Oxygen Production in the Subtropical Pacific Ocean (Gas Tracers O2 Prod Subtropical Pacific)

Program
» Ocean Carbon and Biogeochemistry (OCB)

Contributors	Affiliation	Role
Hamme, Roberta C.	University of Victoria (UVic)	Principal Investigator, Contact
Emerson, Steven R.	University of Washington (UW)	Co-Principal Investigator
Jenkins, William J.	Woods Hole Oceanographic Institution (WHOI)	Co-Principal Investigator
Nicholson, David P.	University of Washington (UW)	Co-Principal Investigator
Rauch, Shannon	Woods Hole Oceanographic Institution (WHOI BCO-DMO)	BCO-DMO Data Manager

Abstract
Inert gases dissolved in the ocean are powerful tracers of the impact of physical processes on gases, particularly air-sea gas exchange (by both diffusive and bubble-meditated processes), temperature change, atmospheric pressure variation, mixing between different water masses, and ice processes. We have compiled a global ocean database of dissolved neon, argon, and krypton measurements, supplemented by helium, xenon, and nitrogen/argon (N2/Ar) ratios in some locations. Samples were collected on board multiple research cruises spanning the period 1999 through 2016 and analyzed by mass spectrometry at four different shore-based laboratories (University of Victoria, Woods Hole Oceanographic Institution, University of Washington, and Scripps Institution of Oceanography). Version 2.0 corrects an incorrect sign in the longitude for cruise 33KI20040814:HOT162 in version 1.0. The error in the database does not affect any figures in the publication (doi: 10.1146/annurev-marine-121916-063604).

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Coverage

Spatial Extent: **N**:78.9988 **E**:33.4993 **S**:-68.1081 **W**:154.9495
Temporal Extent: 1999-10-16 - 2016-06-14

Dataset Description

Hamme et al. (2019) Global noble gas and N2/Ar database, version 1.0. These data are a compilation of dissolved noble gas and N2/Ar ratio measurements collected from 1998-2016 in locations spanning the globe.

This database contains the data on dissolved gas measurements published in:
Hamme, R. C., Nicholson, D. P., Jenkins, W. J., & Emerson, S. R. (2019). Using Noble Gases to Assess the Ocean's Carbon Pumps. Annual Review of Marine Science, 11(1), 75–103. doi:10.1146/annurev-marine-121916-063604

Data Originators: Roberta Hamme, William Jenkins, Steven Emerson, David Nicholson, Rachel Stanley

Date contributed to BCO-DMO: 17 January 2022

Version 2.0 corrects an incorrect sign in the longitude for cruise 33KI20040814:HOT162 in version 1.0. The error in the database does not affect any figures in the publication.

This data is provided free for educational and non-profit research purposes. We ask that you appropriately cite Hamme et al. (2019) Annual Review of Marine Science in any work that uses this database. Please also send an e-mail to rhamme@uvic.ca, letting her know that you have downloaded the data, so that she can keep you apprised of any further corrections or changes. If you discover what you believe to be an error in the database, it is your responsibility to send an e-mail to me at rhamme@uvic.ca before using the data in a publication.

Both MATLAB .mat databases and comma-delimited .csv text files were provided to BCO-DMO. For the flat, ASCII version (csv) use the "Get Data" button on the BCO-DMO metadata landing page. For convenience, the MATLAB file is also provided as a Supplemental File: Global_Hammeetal2019.mat (400 kb)

These two formats contain identical information. Different cruises can be identified by the sequence number, cruisename, or date.

Secondary data - On some cruises, Ar concentration and N2/Ar ratio measurements were performed at two different labs on separate samples, for inter-calibration purposes. In these cases, data from both labs is given separately with data from the second lab labeled "secondary".

Methods & Sampling

Methods (extracted from original Readme file (.txt), which can also be found under Supplemental Files):

University of Victoria - Water samples were collected through CO2-flushed tubing into evacuated flasks until half-full. The water was equilibrated with the headspace and then removed. Noble gas samples were determined following a method similar to that described in (Hamme, R.C., and J.P. Severinghaus 2007) but with a helium rather than nitrogen balance gas. Gas samples were purified through a -90°C trap to remove water vapor and exposed to a hot getter to remove all but the noble gases. A calibrated aliquot of 38Ar was added along with compressed helium to bring the pressure back up. Samples were then measured for Ar isotopes and Ne/Ar and Kr/Ar ratios on a MAT 253 isotope ratio mass spectrometer. Absolute Ar concentrations were determined by Ar isotope dilution with the added 38Ar, while the ratio measurements were combined with the absolute Ar concentrations to yield Ne and Kr concentrations. Noble gas standards were calibrated relative to air with assumed dry mole fractions of 1.818e-5 for Ne, 9.34e-3 for Ar, and 1.141e-6 for Kr. N2/Ar measurements were determined following the method described in (Emerson et al. 1999). Gas samples were purified though a trap in liquid nitrogen to remove water vapor and carbon dioxide. Samples were then measured for N2/Ar ratios on a MAT 253 mass spectrometer. N2/Ar standard gases were calibrated relative to air with assumed dry mole fractions of 9.34e-3 for Ar and 0.78084 for N2.

Woods Hole Oceanographic Institution - Noble gas samples analyzed at Woods Hole Oceanographic

Institution were determined following variants of the method described in (Stanley R.H.R., B. Baschek, D.E. Lott, and W.J. Jenkins 2009). Water samples were collected into stainless steel containers for cruises in 2008 and prior (Bermuda Atlantic Time-series Study cruises and CLIVAR I6S) or into crimped copper tubes for cruises occurring in 2009 and later. All the dissolved gas was extracted from the water and then purified through a cryotrap to remove water vapor and exposed to a hot getter to remove all the the noble gases. The noble gases were then frozen into two cryotraps, allowing each noble gas to be sequentially released for analysis in a quadrupole mass spectrometer. Noble gas concentrations were determined by peak height manometry for all gases and samples, except the most recent Kr and Xe data measured from the eastern tropical Pacific, which use a new isotope dilution method. Noble gas standards were calibrated relative to air with assumed dry mole fractions of 5.24e-6 for He, 1.818e-5 for Ne, 9.34e-3 for Ar, 1.141e-6 for Kr, and 8.7e-8 for Xe.

Scripps Institution of Oceanography - Water samples were collected through CO2-flushed tubing into evacuated flasks until half-full. The water was equilibrated with the headspace and then removed. Noble gas samples were determined following the method described in (Hamme, R.C., and J.P. Severinghaus 2007). Gas samples were purified through a -90°C trap to remove water vapor and exposed to a hot getter to remove all but the noble gases. A calibrated aliquot of 38Ar was added along with compressed nitrogen to bring the pressure back up. Samples were then measured for Ar isotopes and Kr/Ar ratios on a MAT 252 isotope ratio mass spectrometer. Absolute Ar concentrations were determined by Ar isotope dilution with the added 38Ar, while the ratio measurements were combined with the absolute Ar concentrations to yield Kr concentrations. Noble gas standards were calibrated relative to air with assumed dry mole fractions of 9.34e-3 for Ar, and 1.141e-6 for Kr. N2/Ar measurements were determined following the method described in (Kobashi, T., J.P. Severinghaus, and K. Kawamura 2008). Gas samples were purified though a trap in liquid nitrogen to remove water vapor and carbon dioxide and then through heated copper to remove oxygen. Samples were then measured for N2/Ar ratios on a MAT 252 mass spectrometer. N2/Ar standard gases were calibrated relative to air with assumed dry mole fractions of 9.34e-3 for Ar and 0.78084 for N2.

University of Washington - Water samples were collected through CO2-flushed tubing into evacuated flasks until half-full. The water was equilibrated with the headspace and then removed. Neon samples were determined following the method described in (Hamme, R.C., and S.R. Emerson 2004). A calibrated aliquot of 22Ne was added to the sample flasks before sampling. Gas samples were purified though a trap in liquid nitrogen to remove water vapor and carbon dioxide and then through an activated charcoal trap in liquid nitrogen to remove argon and heavier gases. Samples were then measured for Ne isotopes on a quadrupole mass spectrometer. Absolute Ne concentrations were determined by Ne isotope dilution with the added 22Ne. The spike aliquot was calibrated relative to air with assumed dry mole fractions of 1.818e-5 for Ne. Ar concentration and N2/Ar ratios were determined by two different methods. Samples collected in 2001 and earlier were determined following the method described in (Emerson et al. 1999). Gas samples were purified though a trap in liquid nitrogen to remove water vapor and carbon dioxide. Samples were then measured for N2/Ar and O2/Ar ratios on a MAT 251 mass spectrometer. For the samples collected near Bermuda in 2001, the O2/Ar ratio measurements were combined with absolute O2 concentrations determined by Winkler titration to yield Ar concentrations. More recent Ar concentration and N2/Ar ratio measurements were determined following the method described in (Emerson, S., T. Ito, and R.C. Hamme 2012). Gas samples were purified though a trap in liquid nitrogen to remove water vapor and carbon dioxide and then a calibrated aliquot of 36Ar was added. Samples were then measured for Ar isotopes and N2/Ar ratios on a Delta X/L isotope ratio mass spectrometer. Absolute Ar concentrations were determined by Ar isotope dilution with the added 36Ar. Ar and N2/Ar gas standards were calibrated relative to air with assumed dry mole fractions of 9.34e-3 for Ar and 0.78084 for N2. Through rigorous method inter-comparison and repeated laboratory comparison of oxygen concentration determined by isotope dilution and Winkler titration, Ar concentration samples analyzed by this 36Ar isotope dilution method have been found to be 0.7% too low. Accordingly, the Ar concentration and Ar saturation anomaly data from this method have all be increased by 0.7% in this database. Kr/Ar samples were determined following a method similar to that described in (Hamme, R.C., and J.P. Severinghaus 2007). Gas samples were purified through a -90°C trap to remove water vapor and exposed to a hot getter to remove all but the noble gases. Compressed nitrogen was added to bring the pressure back up. Samples were then measured for Kr/Ar ratios on a MAT 253 isotope ratio mass spectrometer. Noble gas standards were calibrated relative to air with assumed dry mole fractions of 9.34e-3 for Ar, and 1.141e-6 for Kr.

Quality control - Samples measured at University of Victoria, Scripps Institution of Oceanography, and University of Washington were nearly all collected in duplicate. For these samples in this database, only data where both duplicates were analyzed successfully and where their standard deviation was less than three times the pooled standard deviation are included. Noble gas duplicates were required to be within 0.93% of each other for Ne, within 0.28% for Ar, and within 0.35% for Kr. Similarly N2/Ar duplicates were required to be within 0.17% of each other. Both duplicates are present in the database. The exception to this is the N2/Ar data collected in 2007 in the Labrador Sea and analyzed at Scripps Institution of Oceanography. These samples were not collected in duplicate but are present in the database. For samples collected at the Bermuda Atlantic Time-series Study and in the Southern Ocean that were analyzed at Woods Hole Oceanographic Institution, we binned the data by depth for each cruise and removed samples that were outside three times the standard deviation of samples within each depth bin. For the 2010-2011 Atlantic GEOTRACES transect samples that were analyzed at Woods Hole

Oceanographic Institution, we simply removed data where the Ne saturation anomaly was less than -10% or larger than 5%. For the 2013 Pacific GEOTRACES transect samples that were analyzed at Woods Hole Oceanographic Institution, we removed Xe measurements analyzed by peak height manometry, retaining only those analyzed by isotope dilution.

NaN = missing data.

Data Processing Description

BCO-DMO Processing of csv file:
- removed blank rows;
- modified parameter names to conform with BCO-DMO naming conventions (replaced spaces, "/", and "-" with underscores, added a "2" to duplicate column names)
- replaced commas with semi-colons in cruise_name field;
- replaced spaces with underscores in cruise_name field;
- 2022-01-21: replaced "158" with "-158" in the longitude column of cruise 33KI20040814:HOT162:Ka (published as version 2).

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Data Files

File	
global_noble_gases.csv	(Comma Separated Values (.csv), 1.16 MB) MD5:56a718d14600af4f652c4e17d7bebaea
Primary data file for dataset ID 743867	

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Supplemental Files

File	
Global_Hammeetal2019.mat	(MATLAB Data (.mat), 400.10 KB) MD5:fc26353d1128658bf5ae89efadf1e012
Global Noble Gases dataset in MATLAB format (BCO-DMO dataset 743867, version 2). These data are identical to the csv/ASCII file, but provided as a .mat file for convenience.	
Readme_Hammeetal2019_v2.txt	(Octet Stream, 20.74 KB) MD5:8218ab3b232c463ef042b32f00a0681e
Readme file to accompany the Global Noble Gases dataset (BCO-DMO dataset 743867).	

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Related Publications

Emerson, S., Ito, T., & Hamme, R. C. (2012). Argon supersaturation indicates low decadal-scale vertical mixing in the ocean thermocline. Geophysical Research Letters, 39(18). doi:10.1029/2012gl053054 https://doi.org/10.1029/2012GL053054
Methods

Emerson, S., Stump, C., Wilbur, D., & Quay, P. (1999). Accurate measurement of O2, N2, and Ar gases in water and the solubility of N2. Marine Chemistry, 64(4), 337–347. doi:10.1016/s0304-4203(98)00090-5 https://doi.org/10.1016/S0304-4203(98)00090-5
Methods

Gehrie, E., Archer, D., Emerson, S., Stump, C., & Henning, C. (2006). Subsurface ocean argon disequilibrium reveals the equatorial Pacific shadow zone. Geophysical Research Letters, 33(18), n/a–n/a. doi:10.1029/2006gl026935 https://doi.org/10.1029/2006GL026935

General

Hamme, R. C., & Emerson, S. R. (2002). Mechanisms controlling the global oceanic distribution of the inert gases argon, nitrogen and neon. Geophysical Research Letters, 29(23), 35–1–35–4. doi:10.1029/2002gl015273 https://doi.org/10.1029/2002GL015273
General

Hamme, R. C., & Emerson, S. R. (2004). Measurement of dissolved neon by isotope dilution using a quadrupole mass spectrometer. Marine Chemistry, 91(1-4), 53–64. doi:10.1016/j.marchem.2004.05.001
Methods

Hamme, R. C., & Emerson, S. R. (2004). The solubility of neon, nitrogen and argon in distilled water and seawater. Deep Sea Research Part I: Oceanographic Research Papers, 51(11), 1517–1528. doi:10.1016/j.dsr.2004.06.009
General

Hamme, R. C., & Emerson, S. R. (2006). Constraining bubble dynamics and mixing with dissolved gases: Implications for productivity measurements by oxygen mass balance. Journal of Marine Research, 64(1), 73–95. doi:10.1357/002224006776412322
General

Hamme, R. C., & Emerson, S. R. (2013). Deep-sea nutrient loss inferred from the marine dissolved N2/Ar ratio. Geophysical Research Letters, 40(6), 1149–1153. doi:10.1002/grl.50275
General

Hamme, R. C., & Severinghaus, J. P. (2007). Trace gas disequilibria during deep-water formation. Deep Sea Research Part I: Oceanographic Research Papers, 54(6), 939–950. doi:10.1016/j.dsr.2007.03.008
Methods

Hamme, R. C., Emerson, S. R., Severinghaus, J. P., Long, M. C., & Yashayaev, I. (2017). Using Noble Gas Measurements to Derive Air-Sea Process Information and Predict Physical Gas Saturations. Geophysical Research Letters, 44(19), 9901–9909. doi:10.1002/2017gl075123 https://doi.org/10.1002/2017GL075123
General

Hamme, R. C., Nicholson, D. P., Jenkins, W. J., & Emerson, S. R. (2019). Using Noble Gases to Assess the Ocean's Carbon Pumps. Annual Review of Marine Science, 11(1), 75–103. doi:10.1146/annurev-marine-121916-063604
Results

Jenkins, W. J., Lott, D. E., German, C. R., Cahill, K. L., Goudreau, J., & Longworth, B. (2018). The deep distributions of helium isotopes, radiocarbon, and noble gases along the U.S. GEOTRACES East Pacific Zonal Transect (GP16). Marine Chemistry, 201, 167–182. doi:10.1016/j.marchem.2017.03.009
General

Jenkins, W. J., Lott, D. E., Longworth, B. E., Curtice, J. M., & Cahill, K. L. (2015). The distributions of helium isotopes and tritium along the U.S. GEOTRACES North Atlantic sections (GEOTRACES GAO3). Deep Sea Research Part II: Topical Studies in Oceanography, 116, 21–28. doi:10.1016/j.dsr2.2014.11.017
General

Kobashi, T., Severinghaus, J. P., & Kawamura, K. (2008). Argon and nitrogen isotopes of trapped air in the GISP2 ice core during the Holocene epoch (0–11,500 B.P.): Methodology and implications for gas loss processes. Geochimica et Cosmochimica Acta, 72(19), 4675–4686. doi:10.1016/j.gca.2008.07.006
Methods

Loose, B., & Jenkins, W. J. (2014). The five stable noble gases are sensitive unambiguous tracers of glacial meltwater. Geophysical Research Letters, 41(8), 2835–2841. doi:10.1002/2013gl058804 https://doi.org/10.1002/2013GL058804
General

Loose, B., Jenkins, W. J., Moriarty, R., Brown, P., Jullion, L., Naveira Garabato, A. C., … Meredith, M. P. (2016). Estimating the recharge properties of the deep ocean using noble gases and helium isotopes. Journal of Geophysical Research: Oceans, 121(8), 5959–5979. doi:10.1002/2016jc011809 https://doi.org/10.1002/2016JC011809
General

Nicholson, D., Emerson, S., Caillon, N., Jouzel, J., & Hamme, R. C. (2010). Constraining ventilation during deepwater formation using deep ocean measurements of the dissolved gas ratios40Ar/36Ar, N2/Ar, and Kr/Ar. Journal of Geophysical Research, 115(C11). doi:10.1029/2010jc006152 https://doi.org/10.1029/2010JC006152
General

Stanley, R. H. R., Baschek, B., Lott, D. E., & Jenkins, W. J. (2009). A new automated method for measuring noble gases and their isotopic ratios in water samples. Geochemistry, Geophysics, Geosystems, 10(5), n/a–n/a. doi:10.1029/2009GC002429
Methods

Stanley, R. H. R., Jenkins, W. J., Lott, D. E., & Doney, S. C. (2009). Noble gas constraints on air-sea gas exchange and bubble fluxes. Journal of Geophysical Research, 114(C11). doi:10.1029/2009jc005396 https://doi.org/10.1029/2009JC005396
Methods

Weiss, R. F. (1971). Solubility of helium and neon in water and seawater. Journal of Chemical & Engineering Data, 16(2), 235–241. doi:10.1021/je60049a019
General

Weiss, R. F., & Kyser, T. K. (1978). Solubility of krypton in water and sea water. Journal of Chemical & Engineering Data, 23(1), 69–72. doi:10.1021/je60076a014
General

Wood, D., & Caputi, R. (1966). Solubilities of Kr and Xe in fresh and sea water (No. USNRDL-TR-988). Naval Radiological Defence Laboratory, San Francisco. URL: http://www.dtic.mil/dtic/tr/fulltext/u2/631557.pdf
General

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Parameters

Parameter	Description	Units
sequence	a sequential numerical identifier for each cruise, unique to this database.	unitless
cruise_name	a string consisting of: the EXPO number is listed first, followed by a colon, followed by colloquial cruise names, followed by a colon, followed by the ship name.	unitless
latitude	the latitude of the station in degrees North.	decimal degrees
longitude	the longitude of the station in degrees East. Negative numbers indicate degrees West.	decimal degrees
event	number of the event that the water samples were drawn from. Event is used when each cast in a cruise has its own unique number.	unitless
station	number of the station that the water samples were drawn from. Station is used when each station (location) in a cruise has its own unique number but multiple casts occurred at a given station number.	unitless
cast	number of the cast at an individual station that the water samples were drawn from. Cast is used when multiple casts occurred at a given station number.	unitless
niskin	number of the niskin bottle or rosette position that the water samples were drawn from.	unitless
year	year; together the year, month, and day columns are the date that samples were collected.	unitless

month	month; together the year, month, and day columns are the date that samples were collected.	unitless
day	day; together the year, month, and day columns are the date that samples were collected.	unitless
press	pressure in dbar	decibars (dbar)
CTDtemp	in situ temperature measured by the CTD in degrees C on the ITS-90 Temperature Scale.	degrees Celsius
CTDsal	salinity measured by the CTD, expressed on the PSS-78 scale.	unitless
analysis_lab	a number indicating which lab the analyses were performed in. 1 = University of Victoria, 2 = Woods Hole Oceanographic Institution, 3 = Scripps Institution of Oceanography, 4 = University of Washington.	unitless
secondary_analysis_lab	for cruises where Ar concentration or N2/Ar ratio were measured in more than one lab, this number indicates which lab the analyses listed in the "secondary" columns were performed in. 1 = University of Victoria, 2 = Woods Hole Oceanographic Institution, 3 = Scripps Institution of Oceanography, 4 = University of Washington.	unitless
He_conc	dissolved He concentration in umol/kg. These concentration values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	micromoles per kilogram (umol/kg)
He_conc2	dissolved He concentration in umol/kg (duplicate value)	micromoles per kilogram (umol/kg)
Ne_conc	dissolved Ne concentration in umol/kg. These concentration values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	micromoles per kilogram (umol/kg)
Ne_conc2	dissolved Ne concentration in umol/kg (duplicate value)	micromoles per kilogram (umol/kg)
Ar_conc	dissolved Ar concentration in umol/kg. These concentration values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	micromoles per kilogram (umol/kg)
Ar_conc2	dissolved Ar concentration in umol/kg (duplicate value)	micromoles per kilogram (umol/kg)

Ar_conc_secondary	same as for Ar_conc but data is from independent samples collected from the same cruise and analyzed in a second laboratory.	micromoles per kilogram (umol/kg)
Ar_conc_secondary2	same as for Ar_conc2 but data is from independent samples collected from the same cruise and analyzed in a second laboratory.	micromoles per kilogram (umol/kg)
Kr_conc	dissolved Kr concentration in umol/kg. These concentration values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	micromoles per kilogram (umol/kg)
Kr_conc2	dissolved Kr concentration in umol/kg (duplicate value)	micromoles per kilogram (umol/kg)
Xe_conc	dissolved Xe concentration in umol/kg. These concentration values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	micromoles per kilogram (umol/kg)
Xe_conc2	dissolved Xe concentration in umol/kg (duplicate value)	micromoles per kilogram (umol/kg)
Ne_Ar	dissolved Ne/Ar ratio with no units. These ratio values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	unitless
Ne_Ar2	dissolved Ne/Ar ratio with no units (duplicate value)	unitless
Kr_Ar	dissolved Kr/Ar ratio with no units. These ratio values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	unitless
Kr_Ar2	dissolved Kr/Ar ratio with no units (duplicate value)	unitless
N2_Ar	dissolved N2/Ar ratio with no units. These ratio values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	unitless
N2_Ar2	dissolved N2/Ar ratio with no units (duplicate value)	unitless
N2_Ar_secondary	same as for N2_Ar but data is from independent samples collected from the same cruise and analyzed in a second laboratory.	unitless

N2_Ar_secondary2	same as for N2_Ar2 but data is from independent samples collected from the same cruise and analyzed in a second laboratory.	unitless
depth	depth in meters	meters (m)
potential_temp	Potential temperature in degrees C and referenced to the surface.	degrees Celsius
sigma_theta	Potential density of the seawater expressed in sigma units and referenced to the surface.	sigma units
Hesat	Saturation anomaly of He in percent. 0% indicates that the He concentration is equal to that expected at equilibrium for the potential temperature and salinity of the water. ie. Hesat = (He/Heeq - 1) *100 The He saturation anomaly is calculated relative to the solubility curve of Weiss, R.F. (1971) "Solubility of Helium and Neon in Water and Seawater", Journal of Chemical and Engineering Data, 16(2), 235-241. These saturation anomaly values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	unitless (percent)
Hesat2	Saturation anomaly of He in percent (duplicate value)	unitless (percent)
Nesat	Saturation anomaly of Ne in percent. 0% indicates that the Ne concentration is equal to that expected at equilibrium for the potential temperature and salinity of the water. ie. Nesat = (Ne/Neeq - 1) *100 The Ne saturation anomaly is calculated relative to the solubility curve of Hamme, R.C., S.R. Emerson (2004) "The solubility of neon, nitrogen and argon in distilled water and seawater", Deep-Sea Research I, 51(11), p. 1517-1528. These saturation anomaly values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	unitless (percent)
Nesat2	Saturation anomaly of Ne in percent (duplicate value)	unitless (percent)
Arsat	Saturation anomaly of Ar in percent. 0% indicates that the Ar concentration is equal to that expected at equilibrium for the potential temperature and salinity of the water. ie. Arsat = (Ar/Areq - 1) *100 The Ar saturation anomaly is calculated relative to the solubility curve of Hamme, R.C., S.R. Emerson (2004) "The solubility of neon, nitrogen and argon in distilled water and seawater", Deep-Sea Research I, 51(11), p. 1517-1528. These saturation anomaly values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	unitless (percent)
Arsat2	Saturation anomaly of Ar in percent (duplicate value)	unitless (percent)
Arsat_secondary	same as for Arsat but data is from independent samples collected from the same cruise and analyzed in a second laboratory	unitless (percent)

Arsat_secondary2	same as for Arsat2 but data is from independent samples collected from the same cruise and analyzed in a second laboratory	unitless (percent)
Krsat	Saturation anomaly of Kr in percent. 0% indicates that the Kr concentration is equal to that expected at equilibrium for the potential temperature and salinity of the water. ie. Krsat = (Kr/Kreq - 1) *100 Kr saturation anomaly is calculated relative to the solubility curve of Weiss, R.F., and T.K. Kyser (1978) "Solubility of Krypton in Water and Seawater", Journal of Chemical Thermodynamics, 23(1), 69-72. These saturation anomaly values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	unitless (percent)
Krsat2	Saturation anomaly of Kr in percent (duplicate value)	unitless (percent)
Xesat	Saturation anomaly of Xe in percent. 0% indicates that the He concentration is equal to that expected at equilibrium for the potential temperature and salinity of the water. ie. Xesat = (Xe/Xeeq - 1) *100 The Xe saturation anomaly is calculated relative to the solubility curve of D. Wood and R. Caputi (1966) "Solubilities of Kr and Xe in fresh and sea water", U.S. Naval Radiological Defense Laboratory, Technical Report USNRDL-TR-988, San Francisco, CA, pp. 14. These saturation anomaly values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	unitless (percent)
Xesat2	Saturation anomaly of Xe in percent (duplicate value)	unitless (percent)
Ne_Arsat	Saturation anomaly of Ne/Ar ratio in percent. 0% indicates that the Ne/Ar ratio is equal to that expected at equilibrium for the potential temperature and salinity of the water, ie. Ne/Arsat = ((Ne/Ar) / (Neeq/Areq) - 1) * 100. Ne/Ar saturation anomaly is calculated relative to the solubility curves of Hamme, R.C., S.R. Emerson (2004) "The solubility of neon, nitrogen and argon in distilled water and seawater", Deep-Sea Research I, 51(11), p. 1517-1528. These saturation anomaly values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	unitless (percent)
Ne_Arsat2	Saturation anomaly of Ne/Ar ratio in percent (duplicate value)	unitless (percent)
Kr_Arsat	Saturation anomaly of Kr/Ar ratio in percent. 0% indicates that the Kr/Ar ratio is equal to that expected at equilibrium for the potential temperature and salinity of the water, ie. Kr/Arsat = ((Kr/Ar) / (Kreq/Areq) - 1) * 100. Kr/Ar saturation anomaly is calculated relative to the Ne solubility curve of Hamme, R.C., S.R. Emerson (2004) "The solubility of neon, nitrogen and argon in distilled water and seawater", Deep-Sea Research I, 51(11), p. 1517-1528 and the Kr solubility curve of Weiss, R.F., and T.K. Kyser (1978) "Solubility of Krypton in Water and Seawater", Journal of Chemical Thermodynamics, 23(1), 69-72. These saturation anomaly values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	unitless (percent)

Kr_Arsat2	Saturation anomaly of Kr/Ar ratio in percent (duplicate value)	unitless (percent)
N2_Arsat	Saturation anomaly of N2/Ar ratio in percent. 0% indicates that the N2/Ar ratio is equal to that expected at equilibrium for the potential temperature and salinity of the water, ie. N2Arsat = ((N2/Ar) / (N2eq/Areq) - 1) * 100. N2/Ar saturation anomaly is calculated relative to the solubility curves of Hamme, R.C., S.R. Emerson (2004) "The solubility of neon, nitrogen and argon in distilled water and seawater", Deep-Sea Research I, 51(11), p. 1517-1528. These saturation anomaly values are from individual samples. Where a duplicate from the same Niskin was collected and analyzed, the duplicate's value is listed in the second column with the same label appended with "2".	unitless (percent)
N2_Arsat2	Saturation anomaly of N2/Ar ratio in percent (duplicate value)	unitless (percent)
N2Arsat_secondary	same as for N2_Arsat but data is from independent samples collected from the same cruise and analyzed in a second laboratory.	unitless (percent)
N2Arsat_secondary2	same as for N2_Arsat2 but data is from independent samples collected from the same cruise and analyzed in a second laboratory.	unitless (percent)
Date	Date in format YYYY-MM-DD	unitless

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Instruments

Dataset-specific Instrument Name	MAT 253 isotope ratio mass spectrometer
Generic Instrument Name	Isotope-ratio Mass Spectrometer
Generic Instrument Description	The Isotope-ratio Mass Spectrometer is a particular type of mass spectrometer used to measure the relative abundance of isotopes in a given sample (e.g. VG Prism II Isotope Ratio Mass-Spectrometer).

Dataset-specific Instrument Name	MAT 252 isotope ratio mass spectrometer
Generic Instrument Name	Isotope-ratio Mass Spectrometer
Generic Instrument Description	The Isotope-ratio Mass Spectrometer is a particular type of mass spectrometer used to measure the relative abundance of isotopes in a given sample (e.g. VG Prism II Isotope Ratio Mass-Spectrometer).

Dataset-specific Instrument Name	MAT 251 mass spectrometer
Generic Instrument Name	Isotope-ratio Mass Spectrometer
Generic Instrument Description	The Isotope-ratio Mass Spectrometer is a particular type of mass spectrometer used to measure the relative abundance of isotopes in a given sample (e.g. VG Prism II Isotope Ratio Mass-Spectrometer).

Dataset-specific Instrument Name	Delta X/L isotope ratio mass spectrometer
Generic Instrument Name	Isotope-ratio Mass Spectrometer
Generic Instrument Description	The Isotope-ratio Mass Spectrometer is a particular type of mass spectrometer used to measure the relative abundance of isotopes in a given sample (e.g. VG Prism II Isotope Ratio Mass-Spectrometer).

Dataset-specific Instrument Name	quadrupole mass spectrometer
Generic Instrument Name	Mass Spectrometer
Generic Instrument Description	General term for instruments used to measure the mass-to-charge ratio of ions; generally used to find the composition of a sample by generating a mass spectrum representing the masses of sample components.

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Deployments

18HU20110506

Website	https://www.bco-dmo.org/deployment/719854
Platform	CCGS Hudson
Report	https://datadocs.bco-dmo.org/d3/data_docs/N2Ar_Deep_Tracer/cruise_rpt_ar07w_18HU20110506do.txt
Start Date	2011-05-06
End Date	2011-05-28
Description	WOCE Line AR7W cruise

18HU20150504

Website	https://www.bco-dmo.org/deployment/720001
Platform	CCGS Hudson
Start Date	2015-05-04
End Date	2015-05-24

18DL20150710

Website	https://www.bco-dmo.org/deployment/719857
Platform	CCGS Amundsen
Report	https://datadocs.bco-dmo.org/d3/data_docs/N2Ar_Deep_Tracer/geotraces_canadian_cruise_report_gn02_gn03_and_figs.pdf
Start Date	2015-07-10
End Date	2015-08-20
Description	A GEOTRACES cruise in the Canadian Arctic

18HU20160430

Website	https://www.bco-dmo.org/deployment/719999
Platform	CCGS Hudson
Start Date	2016-04-30
End Date	2016-05-24

JPT_2009-03

Website	https://www.bco-dmo.org/deployment/529644
Platform	CCGS John P. Tully
Report	http://dmoserv3.whoi.edu/data_docs/ENP_viral_community/cruise_reports/Tully_2009-03_cruise_report.pdf
Start Date	2009-01-27
End Date	2009-02-10

JPT_2009-09

Website	https://www.bco-dmo.org/deployment/529648
Platform	CCGS John P. Tully
Report	http://dmoserv3.whoi.edu/data_docs/ENP_viral_community/cruise_reports/Tully_2009-09_cruise_report.pdf
Start Date	2009-06-06
End Date	2009-06-23

JPT_2009-10

Website	https://www.bco-dmo.org/deployment/529654
Platform	CCGS John P. Tully
Report	http://dmoserv3.whoi.edu/data_docs/ENP_viral_community/cruise_reports/Tully_2009-10_cruise_report.pdf
Start Date	2009-08-18
End Date	2009-09-04

18HU20070510

Website	https://www.bco-dmo.org/deployment/719851
Platform	CCGS Hudson
Report	https://datadocs.bco-dmo.org/d3/data_docs/N2Ar_Deep_Tracer/cruise_rpt_ar07w_18HU20070510do.pdf
Start Date	2007-05-10
End Date	2007-05-27
Description	WOCE Line AR7W cruise

OC449-02

Website	https://www.bco-dmo.org/deployment/58665
Platform	R/V Oceanus
Start Date	2008-08-06
End Date	2008-09-04
Description	R/V Oceanus Voyage #449, Leg II was a trans-Atlantic transect from Bridgetown, Barbados to Porto Grande, Cape Verde (5-20 degrees North, 20-58 degrees West). The main scientific objective was to test the hypothesis that the continental margin of northwest Africa provides a significant subsurface supply of iron to the open eastern tropical Atlantic. Measurements include: CTD profiles, U/W Tow Fish Water Sampler, Trace Metal Profiles mostly in upper 1000 meters and one cast to 6000 meters, SeaSoar SeaMac Winch to deploy eleven battery-operated in-situ pumps with sci-provided non-metallic wire off the 01 deck using the side A-frame and SSSG non-metallic block and Gravity Coring WHOI cruise planning synopsis Cruise information and original data are available from the NSF R2R data catalog.

KN199-04

Website	https://www.bco-dmo.org/deployment/58066
Platform	R/V Knorr
Report	http://bcodata.whoi.edu/US_GEOTRACES/AtlanticSection/Cruise_Report_for_Knorr_199_Final_v3.pdf
Start Date	2010-10-15
End Date	2010-11-04
Description	This cruise constitutes the first survey section as part of the U.S. participation in an international program named GEOTRACES. Funding: NSF OCE award 0926423 Science Objectives: To obtain state of the art trace metal and isotope measurements on a suite of samples taken on a mid-latitude zonal transect of the North Atlantic. In particular, sampling targeted the oxygen minimum zone extending off the west African coast near Mauritania, the TAG hydrothermal field, and the western boundary current system along Line W. For additional information, please refer to the GEOTRACES program Web site (https://www.geotraces.org/) for overall program objectives and a summary of properties measured. Science Activities include seawater sampling via GoFLO and Niskin carousels, in situ pumping (and filtration), CTDO2 and transmissometer sensors, underway pumped sampling of surface waters, and collection of aerosols and rain. Hydrography, CTD and nutrient measurements were supported by the Ocean Data Facility (J. Swift) at Scripps Institution of Oceanography and funded through NSF Facilities. They provided an additional CTD rosette system along with nephelometer and LADCP. A trace metal clean Go-Flo Rosette and winch were provided by the group at Old Dominion University (G. Cutter) along with a towed underway pumping system. Additional cruise information is available from the Rolling Deck to Repository (R2R): https://www.rvdata.us/search/cruise/KN199-04 Other Relevant Links: List of cruise participants: [PDF] Cruise track: JPEG image (from Woods Hole Oceanographic Institution, vessel operator) ADCP data are available from the Currents ADCP group at the University of Hawaii: KN199-04 ADCP

TN303

Website	https://www.bco-dmo.org/deployment/499719
Platform	R/V Thomas G. Thompson
Report	http://dmoserv3.whoi.edu/data_docs/GEOTRACES/EPZT/GT13_EPZT_ODFReport_All.pdf
Start Date	2013-10-25
End Date	2013-12-20
Description	A zonal transect in the eastern tropical South Pacific (ETSP) from Peru to Tahiti as the second cruise of the U.S.GEOTRACES Program. This Pacific section includes a large area characterized by high rates of primary production and particle export in the eastern boundary associated with the Peru Upwelling, a large oxygen minimum zone that is a major global sink for fixed nitrogen, and a large hydrothermal plume arising from the East Pacific Rise. This particular section was selected as a result of open planning workshops in 2007 and 2008, with a final recommendation made by the U.S.GEOTRACES Steering Committee in 2009. It is the first part of a two-stage plan that will include a meridional section of the Pacific from Tahiti to Alaska as a subsequent expedition. Figure 1. The 2013 GEOTRACES EPZT Cruise Track. [click on the image to view a larger version] Additional cruise information is available from the Rolling Deck to Repository (R2R): http://www.rvdata.us/catalog/TN303

KN204-01

Website	https://www.bco-dmo.org/deployment/58786
Platform	R/V Knorr
Report	http://bcodata.whoi.edu/US_GEOTRACES/AtlanticSection/STS_Prelim_GT11_Doc.pdf
Start Date	2011-11-06
End Date	2011-12-11
Description	The US GEOTRACES North Atlantic cruise aboard the R/V Knorr completed the section between Lisbon and Woods Hole that began in October 2010 but was rescheduled for November-December 2011. The R/V Knorr made a brief stop in Bermuda to exchange samples and personnel before continuing across the basin. Scientists disembarked in Praia, Cape Verde, on 11 December. The cruise was identified as KN204-01A (first part before Bermuda) and KN204-01B (after the Bermuda stop). However, the official deployment name for this cruise is KN204-01 and includes both part A and B. Science activities included: ODF 30 liter rosette CTD casts, ODU Trace metal rosette CTD casts, McLane particulate pump casts, underway sampling with towed fish and sampling from the shipboard "uncontaminated" flow-through system. Full depth stations are shown in the accompanying figure (see below). Additional stations to sample for selected trace metals to a depth of 1000 m are not shown. Standard stations are shown in red (as are the ports) and "super" stations, with extra casts to provide large-volume samples for selected parameters, are shown in green. Station spacing is concentrated along the western margin to evaluate the transport of trace elements and isotopes by western boundary currents. Stations across the gyre will allow scientists to examine trace element supply by Saharan dust, while also contrasting trace element and isotope distributions in the oligotrophic gyre with conditions near biologically productive ocean margins, both in the west, to be sampled now, and within the eastern boundary upwelling system off Mauritania, sampled last year. Funding: The cruise was funded by NSF OCE awards 0926204, 0926433 and 0926659. Additional cruise information is available from the Rolling Deck to Repository (R2R): https://www.rvdata.us/search/cruise/KN204-01 Other Relevant Links: ADCP data are available from the Currents ADCP group at the University of Hawaii at the links below: KN204-01A (part 1 of 2011 cruise; Woods Hole, MA to Bermuda) KN204-01B (part 2 of 2011 cruise; Bermuda to Cape Verde)

AE1214

Website	https://www.bco-dmo.org/deployment/744114
Platform	R/V Atlantic Explorer
Start Date	2012-06-17
End Date	2012-06-21
Description	Cruise info from R2R: http://www.rvdata.us/catalog/AE1214

LMG1212

Website	https://www.bco-dmo.org/deployment/744168
Platform	ARSV Laurence M. Gould
Start Date	2012-11-04
End Date	2012-11-23
Description	Additional cruise info from IEDA: http://www.marine-geo.org/tools/entry/LMG1212

LMG0411

Website	https://www.bco-dmo.org/deployment/744171
Platform	ARSV Laurence M. Gould
Start Date	2004-09-29
End Date	2004-10-12
Description	Additional cruise info from IEDA: http://www.marine-geo.org/tools/entry/LMG0411

LMG0507

Website	https://www.bco-dmo.org/deployment/744173
Platform	ARSV Laurence M. Gould
Start Date	2005-06-14
End Date	2005-06-28
Description	Additional cruise info from IEDA: http://www.marine-geo.org/tools/entry/LMG0507

TN224

Website	https://www.bco-dmo.org/deployment/744175
Platform	R/V Thomas G. Thompson
Start Date	2008-08-26
End Date	2008-09-17
Description	Additional cruise info from R2R: http://www.rvdata.us/catalog/TN224

KNOX14RR

Website	https://www.bco-dmo.org/deployment/744178
Platform	R/V Roger Revelle
Start Date	2008-02-04
End Date	2008-03-17
Description	Additional cruise info from R2R: http://www.rvdata.us/catalog/KNOX14RR

JC030

Website	https://www.bco-dmo.org/deployment/744479
Platform	RRS James Cook
Start Date	2008-12-26
End Date	2009-01-30
Description	Additional cruise info from BODC: https://www.bodc.ac.uk/resources/inventories/cruise_inventory/report/9354/

JR239

Website	https://www.bco-dmo.org/deployment/744481
Platform	RRS James Clark Ross
Start Date	2010-03-19
End Date	2010-04-24
Description	Additional cruise info from BODC: https://www.bodc.ac.uk/data/documents/cruise/9972/

LSSL2015-06

Website	https://www.bco-dmo.org/deployment/744484
Platform	CCGS Louis S. St-Laurent

MR00-K03

Website	https://www.bco-dmo.org/deployment/744486
Platform	R/V Mirai
Start Date	2000-05-09
End Date	2000-06-09
Description	Additional cruise info: http://www.godac.jamstec.go.jp/darwin/cruise/mirai/mr00-k03/e

KN166-11

Website	https://www.bco-dmo.org/deployment/744488
Platform	R/V Knorr
Start Date	2002-05-30
End Date	2002-07-01
Description	Additional cruise info from R2R: http://www.rvdata.us/catalog/KN166-11

RB0501

Website	https://www.bco-dmo.org/deployment/744491
Platform	NOAA Ship Ronald H. Brown
Start Date	2005-01-11
End Date	2005-02-24
Description	Additional cruise info from CCHDO: https://cchdo.ucsd.edu/cruise/33RO200501

GP2-05-KA

Website	https://www.bco-dmo.org/deployment/744494
Platform	NOAA Ship Ka'imimoana
Start Date	2005-04-05
End Date	2005-05-12
Description	Additional cruise info is available at: http://www.tao.ndbc.noaa.gov/tao/kaimi/previous_ndbc.shtml

MR07-06_Leg1

Website	https://www.bco-dmo.org/deployment/744496
Platform	R/V Mirai
Start Date	2007-10-07
End Date	2007-11-20
Description	Additional cruise info: http://www.godac.jamstec.go.jp/darwin/data/mirai/mr07-06_leg1/navigation/e

BATS_cruises

Website	https://www.bco-dmo.org/deployment/58883
Platform	Multiple Vessels
Report	http://bats.bios.edu/bats-data/
Start Date	1988-10-20
Description	Bermuda Institute of Ocean Science established the Bermuda Atlantic Time-series Study with the objective of acquiring diverse and detailed time-series data. BATS makes monthly measurements of important hydrographic, biological and chemical parameters throughout the water column at the BATS Study Site, located at 31 40N, 64 10W.

HOT_cruises

Website	https://www.bco-dmo.org/deployment/58879
Platform	Multiple Vessels
Report	http://hahana.soest.hawaii.edu/hot/
Start Date	1988-10-31
Description	Since October 1988, the Hawaii Ocean Time-series (HOT) program has investigated temporal dynamics in biology, physics, and chemistry at Stn. ALOHA (22°45' N, 158°W), a deep ocean field site in the oligotrophic North Pacific Subtropical Gyre (NPSG). HOT conducts near-monthly ship-based sampling and makes continuous observations from moored instruments to document and study NPSG climate and ecosystem variability over semi-diurnal to decadal time scales. A cruise inventory with additional metadata can be found here: https://hahana.soest.hawaii.edu/hot/cruises.html

Line-P_cruises

Website	https://www.bco-dmo.org/deployment/744516
Platform	CCGS John P. Tully
Description	Line P is an oceanic transect of 26 periodically sampled stations running from southern Vancouver Island to "Ocean Station Papa", situated at 50°N 145°W. Ocean (Weather) Station Papa, station P26, was originally operated as an ocean weather station from December of 1949 through 1981. After 1981, the Line-P / Station-P program was then taken over by the Institute of Ocean Sciences from Fisheries and Oceans Canada (DFO). While hydrographic (CTD-based) measurements are made at all of the 26 sites, water chemistry (bottle rosettes) and plankton (bongo) samples are only made at stations P4, P8, P12, P16, P20, and P26. Of those expanded sampling variables sites, all but P8 are featured in this web summary. See: https://www.st.nmfs.noaa.gov/copepod/time-series/ca-50903/ https://www.waterproperties.ca/linep/index.php

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Project Information

Carbon Dioxide Dynamics in Mode Water of the North Atlantic Ocean (CarboMODE)

Coverage: North Atlantic

from the NSF proposal abstract

The formation of mode waters, like Eighteen Degree Water (EDW) in the North Atlantic Ocean, is important for driving ocean circulation, ventilating and transferring biogeochemical properties to the ocean interior. Recent studies suggest that EDW plays an important role in setting the nutrient reservoir of the subtropical gyre [Jenkins and Doney, 2003; Doney and Jenkins, 2004; Palter et al., 2005], with significant implications for nutrient and carbon dynamics, and productivity in the subtropical gyre of the North Atlantic. In addition, EDW has a potentially important role in the ocean uptake and decadal variability of atmospheric CO2 [Bates et al., 2002].

In this study, researchers at the Bermuda Biological Station for Research (BBSR) and the Woods Hole Oceanographic Institution (WHOI) hope to achieve a better quantitative and mechanistic understanding of the CO2 dynamics in EDW. The work leverages the 2006-2007 field program and improved understanding about the physics of EDW that an NSF sponsored field project, CLImate MOde water Dynamics Experiment (CLIMODE) will gain. The main question posed in CarboMODE is "What is the oceanic uptake and fate of CO2 in EDW in the North Atlantic Ocean?" From this general question, more specific questions are raised, including: (1) What is the air-sea CO2 flux during wintertime EDW formation? (2) What are the relative contributions from vertical/lateral mixing, advection/stirring, air-sea CO2 gas exchange and biological depletion of CO2 due to net community production during EDW formation that influence the DIC properties of EDW? (3) What is the dissolved inorganic carbon (DIC) content of EDW upon subduction (injection) into the subtropical gyre and what is the overall flux? (4) How does the formation of EDW impact the subsurface inorganic carbon reservoir and air-sea CO2 fluxes in the subtropical gyre of the North Atlantic Ocean? (5) What is the fate of inorganic carbon in EDW as it advects away from the region of formation and how does subsurface remineralization contribute to the DIC content of EDW?

In addressing these questions, the investigators propose will collect inorganic carbon data in 2007 as part of the CLIMODE project. Their contribution to the CLIMODE (and CarboMODE) project will be measurements of DIC, Total Alkalinity (TA) and underway pCO2 (i.e., seawater and air pCO2). Although focused on physics, the observational and modeling program framed by CLIMODE's questions and hypotheses fortuitously provide a timely and unique opportunity to address questions raised about CO2 dynamics (and related issues concerning nutrient and dissolved oxygen dynamics). Synthesis and modeling of several different datasets, including the 2007 CLIMODE field surveys of EDW, CO2 data collected from a 2006 CLIMODE cruise, a 4 day northward extension of the BATS Bermuda-Puerto Rico annual transect, and surface seawater pCO2 (and DIC and alkalinity) data collected twice a week in the region of EDW formation from the Volunteer Observing Ship (VOS) MV Oleander (funded by NOAA COSP), form the nucleus for addressing relevant CarboMODE questions.

Measurement of Helium Isotopes, Tritium, Noble Gases, and Radiocarbon (EPZT Noble Gases He Tritium)

Coverage: Oxygen minium zone; East Pacific Rise

The biogeochemical cycling of trace elements and isotopes (TEIs) in the marine environment is an important research area within the context of global change that motivates the International GEOTRACES program. Some trace elements are known to play potentially important roles as micronutrients in biological cycling, particularly in regard to enzymatic and catalytic processes in the marine environment. Radioisotopes, transient tracers, and noble gases are valuable tracers of these and related processes, and of the ocean?s interaction with the atmosphere and the solid earth, which in turn play a role in shaping many trace element distributions within the ocean.

According to the GEOTRACES Science Plan, the guiding mission of the GEOTRACES program is "to identify processes and quantify fluxes that control the distributions of key trace elements and isotopes in the ocean". The key observational strategy for GEOTRACES is an internationally-coordinated global-scale ocean survey of key TEIs. The second US GEOTRACES section, set for the Eastern South Pacific in 2013, is aimed at the characterization of key processes in an oxygen minimum zone (OMZ), as well as a major abyssal hydrothermal plume extending westward from the East Pacific Rise.

To help achieve these goals, with support from this grant, a research team at the Woods Hole Oceanographic Institution will collaborate with other GEOTRACES investigators on the Eastern South Pacific expedition to measure a suite of tracers useful for interpreting the rest of the synoptic TEI data. Specifically, the team will make measurements of the noble gases, helium isotopes, tritium, and radiocarbon include in order to: (1) quantify ventilation, circulation, and diapycnal mixing in the OMZ to enable estimation of fluxes and transformation rates of key TEIs; (2) determine upwelling rates in the oxygen minimum zone (OMZ) over a range of timescales to constrain the fluxes of biogeochemically important properties; (3) estimate hydrothermal fluxes of key TEIs using 3He as a flux gauge, and also use 3He as a measure of downstream dilution in the hydrothermal plume; (4) use radiocarbon to estimate abyssal remineralization rates for key TEIs; and (5) probe for evidence of off-axis contribution of hydrothermal processes to TEI distribution. The collective effort will allow marine geochemists to understand mechanistically and quantitatively how a variety of physical, chemical, and biological processes join to determine the distribtuion of TEIs in the ocean.

It has been argued that anthropogenic influence on the global cycles of many elements is emerging as significant. As outlined in the International GEOTRACES Science Plan, the broader impacts of this activity include both an important "baseline snapshot" of the biogeochemical state of the oceanic environment, and a quantitative improvement in the characterization and understanding of important processes in the marine environment. Both of these build a foundation for improved models and quantitative predictions of the oceanic response and role in global change and climate, particularly with anthropogenic forcing. For example, recent evidence of "ocean deoxygenation" has profound implications for marine biologic response. In particular, the evolving state of marine OMZs represents an important biogeochemical "climate canary". A key benefit of diagnosing trace metal dynamics and response to changing redox conditions is the improvement in prognostic capabilities of coupled ocean-atmosphere biogeochemical models for global change.

The Marine Dissolved N2/Ar Ratio, A Tracer for Deep Ocean Denitrification? (N2:Ar Deep Tracer)

Coverage: Global oceans

The role of nitrate in the ocean carbon cycle and its relatively short residence time make it crucial to understand the marine nitrogen cycle; however, there is currently insufficient experimental evidence to accurately determine present day fluxes. Denitrification and nitrogen fixation are the main sink and source for dissolved inorganic nitrogen in the sea.

In this study a research team at the University of Washington will collaborate with colleagues at the University of Victoria to study changes in the N2/Ar ratio in seawater caused by denitrification. Previous research has demonstrated the utility of this tracer in the oxygen minimum zones of the Pacific and Indian Ocean, but they will investigate observed changes in the "background" distribution of the ratio. The investigators already have unpublished data that indicate the N2/Ar ratio increases by about 0.5 % from the Atlantic to Pacific Oceans in waters below 1000 meters. If this increase is assumed to be caused by denitrification in deep ocean sediments it amounts to roughly 80 Tg/yr of denitrification. This is a significant portion of estimated global denitrification (between 200 and 400 Tg/yr) and within the range of the largely untested predictions of deep-ocean sediment denitrification using global sediment diagenesis models. Presently it is not possible to unequivocally attribute the observed deep water column N2/Ar increase to denitrification because it could also be caused by deep-water

formation processes in the Antarctic.

The investigators will separate the fraction of the N2/Ar ratio increase due to the physical processes of atmosphere or ice-water interaction from that due to denitrification by measuring other noble gas ratios (primarily Ne/Ar and Kr/Ar) that change only in response to ocean surface cooling and bubble processes. They will measure deep water-column profiles of N2/Ar, Ne/Ar and Kr/Ar in strategically-located sites where there are ships of opportunity: the Labrador Sea, the North Atlantic at the Bermuda time-series site, the Drake Passage, the Indian Ocean south of Madagascar, the subtropical North Pacific at the Hawaii Ocean time-series site, and the subarctic North Pacific at Station P. Preliminary measurements of all of the gas ratios have been made, and extensive testing has been done to identify sources of contamination in the sampling methods. This proposal involves a two-laboratory collaboration to make it possible to sample a large number of ocean sites, minimize atmospheric contamination by rapid sample analysis, and create maximum accuracy through laboratory intercalibration.

Broader Impacts: This project will promote international ocean science collaboration between the U.S.and Canada. It will support the research of an assistant professor to apply analytical methods that she has helped develop to an important problem in oceanography. A PhD candidate at the University of Washington will be trained in the area of chemical oceanography using analytical methods of gas ratio and isotope ratio mass spectrometry.

Characterizing the Formation, Nature, and Export of Weddell Sea Bottom Water using Noble Gases and Transient Tracers (Weddell Sea Tracers)

NSF Award Abstract:

Intellectual Merit: It is commonly accepted that since at least the last glacial maximum, the substantial millennial-timescale changes in global climate have been caused by, or at least associated with abrupt changes in the oceanic Meridional Overturning Circulation (MOC). There is the lingering suspicion that perhaps the ultimate trigger of the climate transients may lie in the southern hemisphere. Dense waters formed by buoyancy modification on Antarctic shelf regions leave the shelves and sink to comprise the major water mass complex known as Antarctic Bottom Water (AABW). AABW, the coldest and densest water to play a role in the MOC, in turn enters all of the major ocean basins and thereby closes the southern end of the MOC loop. The Weddell Sea features prominently in the production of AABW, where interaction between seawater and the floating ice-shelves produces a unique pre-cursor to AABW by a combination of processes, including) strong heat extraction at ice-edge polynyas, sea-ice formation and export, melting of glacial ice at the grounding line, and formation and deposition of sub-marine sea-ice. These processes not only produce oceanographically and climatically significant injections of fresh water into the AABW pre-cursor, but are hypothesized to have significant impact on its dissolved noble gas composition. We propose to use high precision measurements of the latter as a diagnostic tool of the magnitude of these processes.

The investigator will participate in a British research cruise ANDREX which is a section connecting the CLIVAR (CLImate VARiability and predictability Program) repeat line I6S with the Antarctic Peninsula in early 2009. The cruise follows the northern rim of the Weddell Sea gyre, and is ideally situated to study the exchange of water masses across the Antarctic Circumpolar Current. A combination of noble gases, transient tracers (tritium and radiocarbon) along with CFCs, stable isotopes, 3He, and traditional hydrographic measurements will be used to place constraints on an oceanographically and climatically important region.

Broader Impacts: This project involves the development and use of novel oceanographic tracers and the application of more traditional tracers in new ways to characterize water mass transformation processes that are of fundamental importance in the operation of the global climate system. The new insights into these processes will provide valuable guidance in the design and construction of the next generation of coupled ocean-atmosphere climate models, which will be of strategic importance in facing the broad range of economic, policy, and societal issues created by climate change. The data set produced in this work will be submitted to the appropriate data centers/repositories to be made available to modelers and climate scientists to guide future research efforts and to evaluate or test existing and future climate models.

Measuring Diapycnal Mixing in the Upper Ocean therMocline using Noble Gas Supersaturation (Measuring Diapycnal Mixing)

NSF Award Abstract:

In this project, researchers at the University of Washington School of Oceanography will develop a new method of constraining the rate of diapycnal (cross-isopycnal) mixing in the ocean using the natural distributions of dissolved noble gases. They will apply this method to determine the diapycnal mixing rate in the ventilated thermocline of the subtropical oceans where there is long-standing uncertainty about the physical mechanisms supplying nutrients to the euphotic zone. Noble gases are not affected by biology, so their distribution in the ocean is determined purely by physical processes. Because the equilibrium concentrations of these gases are non-linear functions of temperature, mixing between waters equilibrated with the atmosphere at different temperatures induces a supersaturation in the gases. Advances in analytical methodology have recently made it possible to measure this mixing signal, and a theoretical basis for understanding it has also just been developed. The theory indicates that noble gas supersaturation accumulates over the time since the water parcel left the surface and that it is most sensitive to diapycnal mixing in the ventilated thermocline of the ocean. Thus, this tracer records the effect of diapycnal mixing over time scales of decades and compliments purposeful tracer release experiments that last months to a year and whole-ocean analyses of thermocline mixing that represent hundreds of years.

The project will combined analytical and theoretical research. The research team will measure the concentrations of Ne, Ar, Kr and Xe in transects through three sections of the world's ventilated thermocline. Two meridional sections through the central North Pacific and eastern South Pacific and a zonal transect across the southern North Atlantic cross contrasting regions where we expect the noble gas tracers to reveal different degrees of supersaturation due to diapycnal mixing. The theoretical/modeling aspect of the proposal focuses on using a series of ocean global circulation model runs to help separate the different physical processes causing noble gas supersaturation. The model will then be used to determine the effect of the diapycnal mixing rates deduced from the inert gas tracers on the transport of nutrients to the euphotic zone in the subtropical oceans. Using this interdisciplinary approach the team will evaluate the utility of noble supersaturation as a tracer of diapycnal mixing in the ocean thermocline and advance our understanding of a classic problem in oceanography.

The project is expected to have a number of broader impacts. By developing a new method of quantifying diapycnal mixing rates in the ocean's thermocline, this project should help to solve the many issues that depend on this fundamental quantity, from determining biological productivity and its controls to understanding the driving forces behind the overturning circulation. Better constraints over mixing rates and wide dissemination of the observational dataset for other data/model comparisons will lead to improved predictions for anthropogenic CO2 uptake by the ocean and for changes in biological productivity caused by global warming, both topics of clear interest to society. The project will also promote education by involving a graduate student that will be jointly advised by the principle investigators and will enhance international scientific collaboration by establishing joint field and analytical research with Japanese and Canadian colleagues.

GEOTRACES Atlantic Section: Measurement of Helium Isotopes and Tritium (NAT He and Tritium)

NSF Award Abstract:
This award is funded under the American Recovery and Reinvestment Act of 2009 (Public Law 111-5).

The guiding mission of the GEOTRACES program is to identify processes and quantify fluxes that control the distributions of key trace elements and isotopes in the ocean. The key observational strategy for GEOTRACES is an internationally-coordinated global-scale ocean survey of key trace elements and isotopes (TEIs), and the first U.S. section as part of that survey is in the North Atlantic. Knowing rates and fluxes is a vital step in the development of mechanistic and predictive models of ocean biogeochemical cycles of TEIs, particularly within the framework of global change (both past and future). Much of what we have learned about large scale oceanic rates and fluxes has been inferred from the observation and modeling of tracer distributions, both radioactive and transient. Measurement of appropriate transient tracers alongside of core TEIs would be an effective strategy for achieving GEOTRACES goals.

In this project, researchers at the Woods Hole Oceanographic Institution will make helium isotope and tritium measurements to provide useful biogeochemical rate information for the more centrally important TEI measurements made on the first U.S. GEOTRACES global survey section. The primary contributions that tritium and 3He measurements can make to the program include: (1) Quantifying transit timescales and TEI dilution in the MOC: 3H and 3He are useful tracers for determining deep western boundary current tracer transport rates and interior mixing dilution scales, an important issue for many TEIs; (2) A shallow water chronometer: Using the tritium-3He clock, the time elapsed since fluid parcels have been subducted on timescales ranging from 6 months to several decades can be determined; (3) A TEI thermocline reflux gauge: 3He is a unique "nutrient-like" transient tracer that can be used as a "flux gauge" to determine the rates at which thermocline-remineralized TEIs are returned to the upper ocean; and (4) Gauging TEI hydrothermal dilution scales: Volcanic 3He injected during hydrothermal activity is a powerful conservative tracer of dilution in these plumes, allowing diagnosis of nonconservative behavior in some TEIs, and permitting flux estimates associated with hydrothermal activity on

basin and global scale.

Broader Impacts: The proposed work is in support of the GEOTRACES program, and as such contributes to the broader societal goals and intellectual objectives espoused by that program. The primary issues related to this are pertinent to understanding the carbon cycle and predicting/mitigating climate change, as well as the marine food web and anthropogenic impacts on the oceans.

Tracers of Biological Productivity and Gas Exchange (Tracers of Bio Prod and Gas Exchange)

NSF Award Abstract:

OCE-0242139

The export of carbon from the surface of the ocean is one of the processes controlling the partial pressure of carbon dioxide (pCO2) of the atmosphere, which greatly influences the climate of the Earth. Changes in atmospheric pCO2 over glacial time scales are often interpreted as a response to changes in the ocean's biological carbon pump. Models of the carbon pump are limited by our understanding of mechanisms that control it in different areas of the ocean. Satellite color images hold great promise for determining the biological pump globally, but only if the images can be ground truthed by field measurements. To date this calibration has been achieved in only four places in the ocean: the long-term time series locations and parts of the Equator.

In this project, researchers at the University of Washington will develop experimental methods of improving our knowledge of the ocean.s biological carbon pump. The research program is twofold. First they will deploy four oxygen sensors and a GTD on the new mooring at HOT to measure a profile of O2 in the euphotic zone and the surface concentrations of N2. They believe that this will be sufficient to determine the net biological oxygen production. Two methods will be tested for calibrating the oxygen sensors in situ. This research will develop methods to determine the oxygen mass balance (and hence biological carbon pump) on moorings at other locations in the ocean.

The second, and much smaller, aspect of the project builds on the research team's analytical ability to determine N2, Ar and Ne in seawater. They will conduct a field program to study the concentrations of these gases as a function of wind speed on several short cruises in the Drake Passage of the Southern Ocean. The goal is to develop a correlation between bubble flux and wind speed. This knowledge could be used to characterize the bubble process in locations where it is not possible to measure these gases and to improve estimates of the biologically produced oxygen flux from the ocean using climatological surface ocean oxygen concentrations.

Broader impacts of this proposal include the benefits to society that will result from understanding the marine biological pump well enough to incorporate it into ocean-atmosphere models that will be used to predict future climate. The proposal also promotes education of a graduate student who will work on the project.

Is There an Ocean Primary Production Paradox(OP3)? (OP3)

NSF Award Abstract:

OCE-0221247

Primary production and remineralization in oligotrophic ocean waters like those around Bermuda are phenomena of central importance in the ocean carbon-cycle and figure prominently in climate change impact modeling. Geochemical constraints on primary production at Bermuda, characterized by annual and longer time-scales and based on three fundamentally different systems, lead to quantitatively consistent estimates of new, net community and export production. This agreement between the three types of primary production would at first seem to be expected on such time-scales, but leads to the basic "Redfield Paradox ": nutrients advected or mixed upward into the euphotic zone must carry with them an associated oxygen debt (AOU) and dissolved inorganic carbon sufficient to negate largely the observed seasonal photosynthetic oxygen buildup and carbon drawdown. An exhaustive consideration of various explanations and scenarios that can be offered fail to explain the observations -- a dilemma here referred to as the "Ocean Primary Production Paradox (OP3)".

A team of researchers at the Woods Hole Oceanographic Institution will re-examine the OP3 by simultaneously and definitively measuring all three geochemical systems over a period of three to four years. These three systems are,

specifically, euphotic zone oxygen production, aphotic zone oxygen consumption, and nutrient flux-gauge determinations. The euphotic zone oxygen system will be constrained by the time-series measurement of the full suite of noble gases (He-Xe) plus O2 and N2,with emphasis on precision measurements of O2 and Ar (to 0.1%),the latter as a biogenic analog of oxygen. The other gases will be used to more completely constrain and refine the air-sea gas exchange and upper ocean model.

Aside from addressing fundamental problem in ocean biogeochemistry, this work is expected to have considerably broader impact in the field of ocean geochemistry by providing the oceanographic community with new sampling technology (the noble gas sampler) that can be used in a broad variety of biogeochemical problems. The design and expertise will be made freely available to those who request it.

The Biological Carbon Pump in the Subtropical North Pacific Ocean: Mechanisms of Nutrient Supply (C Pump in Subtropical N Pacific)

NSF Award Abstract:

OCE-9906922

The subtropical gyres occupy a large fraction of the world ocean and until recently, the common view was that these vast nutrient-depleted regions support only a small amount of primary productivity. However, this view is changing and it appears that production in these areas is important. Thus it is important to understand the mechanism by which nutrients are supplied to these areas. To this end, this project will seek to improve estimates of the mechanisms of nutrient transport to the euphotic zone, and also better constrain the magnitude of the carbon pump. The three main elements of this proposal are improvment in the continuous measurements of oxygen and N2 on the HOT mooring, ship-of-opportunity measurements of DOP (dissolved organic phosphorus) and DON (dissolved organic nitrogen), and measurements of neon to clarify the mechanism of bubble-induced gas exchange in the O2 budget. The goal is to determine the quantitative importance of intermittment diapycnal and surface transport of phosphorus, and to improve mass balance estimates of net biological oxygen production.

Net Biological Oxygen Production at the Japanese JGOFS Time-Series Station (Net Bio O2 Prod JGOFS)

NSF Award Abstract:

OCE-9819181

Primary production in the ocean is important not only for the functioning of the marine ecosystem but also for its pivotal role in regulating sea-air exchange of carbon dioxide, the most important atmospheric greenhouse gas. In this study, the principal investigator will use an indirect method to determine the net annual oxygen production in the northwest Pacific Ocean by measuring eleven profiles of O2, N2, and Ar concentrations in the upper ocean at the Japanese Joint Global Ocean Flux Study (JGOFS) time-series station. The time-series station is located in what is probably the most biologically productive region of the North Pacific, and the oxygen flux estimates are expected to provide the first good estimates of the regional primary production. The PI will be taking advantage of a unique opportunity to participate in Japanese JGOFS cruises in this region between 1998 and 2000.

Gas Tracers of Net Biological Oxygen Production in the Subtropical Pacific Ocean (Gas Tracers O2 Prod Subtropical Pacific)

NSF Award Abstract:
9617487 Emerson Organic carbon export from the euphotic zone of the ocean regulates the CO2 content of the atmosphere and controls the redox balance in ocean chemistry on millenial time scales. One of the fundamental goals of oceanography is to evaluate the organic carbon flux and determine the controlling mechanisms so that system can be modeled well enough to predict responses to changes in forcing. Recent estimates of carbon export by a variety of methods at the U.S. JGOFS time-series stations indicate that the subtropical oceans are

responsible for 25-50 percent of the global ocean new production. Progress in estimating the rate of new carbon export from the euphotic zone in the subtropical north Pacific Ocean now require knowledge of the mechanisms(s) controlling the supply rate of nutrients. Suggestions of diapycnal mixing, horizontal transport of dissolved organic matter, and various biological processes are currently being advanced. The implications of the different mechanisms regarding the coupling of the biological pump and ocean circulation are obvious and hold extremely important consequences for our understanding of the response of the ocean's "biological pump" to physical forcing. This study is designed to test the hypothesis that the mechanism supplying nutrients to the euphotic zone in the subtropical north Pacific is diapycnal transport. Focus will be on two main problems: (1) the role of intermittent transport in supplying nutrients necessary to create the shallow oxygen maximum, and (2) the utility of inert gases as tracers of diapycnal transport in the upper ocean. A fully instrumented deep-sea mooring will soon be deployed at the Hawaii Ocean Time-series (HOT) and can be used to make continuous measurements of oxygen and total gas pressure on the mooring to determine whether formation of the shallow O2 maximum is correlated to short-term intermittent supply of nutrients from below. ***

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Program Information

Ocean Carbon and Biogeochemistry (OCB)

Website: http://us-ocb.org/

Coverage: Global

The Ocean Carbon and Biogeochemistry (OCB) program focuses on the ocean's role as a component of the global Earth system, bringing together research in geochemistry, ocean physics, and ecology that inform on and advance our understanding of ocean biogeochemistry. The overall program goals are to promote, plan, and coordinate collaborative, multidisciplinary research opportunities within the U.S. research community and with international partners. Important OCB-related activities currently include: the Ocean Carbon and Climate Change (OCCC) and the North American Carbon Program (NACP); U.S. contributions to IMBER, SOLAS, CARBOOCEAN; and numerous U.S. single-investigator and medium-size research projects funded by U.S. federal agencies including NASA, NOAA, and NSF.

The scientific mission of OCB is to study the evolving role of the ocean in the global carbon cycle, in the face of environmental variability and change through studies of marine biogeochemical cycles and associated ecosystems.

The overarching OCB science themes include improved understanding and prediction of: 1) oceanic uptake and release of atmospheric CO2 and other greenhouse gases and 2) environmental sensitivities of biogeochemical cycles, marine ecosystems, and interactions between the two.

The OCB Research Priorities (updated January 2012) include: ocean acidification; terrestrial/coastal carbon fluxes and exchanges; climate sensitivities of and change in ecosystem structure and associated impacts on biogeochemical cycles; mesopelagic ecological and biogeochemical interactions; benthic-pelagic feedbacks on biogeochemical cycles; ocean carbon uptake and storage; and expanding low-oxygen conditions in the coastal and open oceans.

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Funding

Funding Source	Award
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